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INDUSTRIAL DIAMOND REVIEW

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Generally Speaking

Diamonds Galore

We are suckers, as regular readers of this column may have gathered, for rumours of diamonds in far-away places; and the best for some time has just come our way, via the *Diamond News* and the *Manchester Evening News*. It tells of a Mancunian recently back from diamond prospecting in northern Brazil, where 'he was one of only two white men to set eyes on a narrow "lost world"—a valley blocked by rocks as big as houses, a valley with diamonds strewn about its floor.' By latest report, the lucky man is now heading back up the Amazon. To quote him: 'We shall go in with a full year's stores and start working it. The theory is that if the river originally went that way it has piled diamonds up. Whoever gets through is going to shovel them up.'

While slightly unhappy about the drop into a minor key—'*theory . . . if*'—at the end, we wish the gentlemen the best of good fortune. We are even prepared to offer some advice on getting the diamonds out of his inaccessible valley: how about a Roc, and a couple of tons of raw meat?

Positioning a Tool

The Diamond Tool Co of South Haven, Michigan, manufacturers of the Coolie-Grinderlap carbide grinder, now offer a new piece of equipment called the Angle-Set mitre gauge, for use on tilt tables of all carbide tool grinders. It can position tools at extremely small or large angles while sharpening, and can be assembled in four different positions to give a complete 180° selection of tool rest positions, as indicated on a calibrated 90° sector dial.

While on the subject of tool grinding, it is of interest to note that a representative of the Caterpillar Tractor Co has broken down tool replacement costs over a six month period, and found that as much as ten per cent could be listed as due to 'human error'. Breaking it down still further, the errors were:

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1. Improper handling—causing nicked cutting edges.
2. Improper application—as, for instance, tapping a tool with a wrench to adjust it in a machine.
3. Improper alignment of the tool in the machine.
4. Running a tool beyond its normal cutting life—this requiring additional grinding, and reducing the number of times the tool can be re-sharpened.

It's Softer when you Pull It

The probability that stresses may affect hardness readings has been occasionally suggested in the past. A paper to the 1957 annual meeting of ASME, held in New York in December, has described tests on mild steel and aluminium to determine hardness under uniform stress as well as bending (gradient) stress, and during states of stress below and at the yield point of the metal. The results bore out the theory: the materials became softer under tension, and harder under compression.

Craftsmen

The Editor of *Product Engineering*, E. J. Tangerman, recently wrote an obituary for two New England craftsmen of the old school, one of whom once lapped a perfect surface, and proved it by wiping on a 5-inch optical flat—which he subsequently couldn't get off. This was 'Accurate Bill' Nichols ; the other, to whom Nichols paid homage as the better craftsman, was David Mann, of Lincoln, Mass., who specialized, among other things, in the diamond engraving of vernier scales.

In this kind of work, the secret is to set the machine, and then make sure that it is not disturbed until it has finished its cycle, which can take as long as a week. The apparatus must not only be completely free of vibration, but also of the slightest heat variation, such as would be caused by the presence of an observer. Any infringement of these stipulations, and you wind up with scrap.

Mann's solution was to set up his dividing engine in a tiny room below the floor of his basement. With insulation against building heat, a room in the ground will hold a constant temperature of from 50 to 55° F, depending on the local ground-water temperature. This he raised to 70° F with a small gas jet. And finally he got his really close temperature adjustment with the aid of an electric light bulb, controlled by a 0.1° F thermostat.

This makes entirely credible another story: that he defied the US Navy when they wanted to have acceptance numbers stamped on some high-precision diamond scribers he was making for them. The Navy sent in an admiral, but they lost the battle all the same. The numbers were painted on.

One Micron Wire?

The spiral growth type of mechanism, operative with crystals formed from slightly supersaturated solutions, results in a formation with a screw axis extending through it, perpendicular to the planes of growth. The region surrounding this axis, being one of imperfect orientation, is more subject to chemical attack than the remainder. This has now been used as the basis of a method for producing crystals (*eg* silicon carbide) with holes ranging from one to several hundred microns in diameter. Such crystals can be used as dies for drawing wire, or as apertured windows in x-ray and electron diffraction techniques.

In an English Accent

Even the officers of a certain well known diamond sales organization have a social life. It's recorded that one of them once found himself, at a ball, dancing with an altogether lovely young thing—to use an obsolescent term, a deb. 'Tell me,' she asked him, '. . . what do you do?' 'I sort diamonds,' he modestly replied. The answer transformed her: 'But how wonderful! How utterly fascinating! You must come and meet my people.' The music ended, and she took him away and introduced him to her parents and friends. 'And now,' she commanded, 'you must tell us all about it.

'Tell us just how you salt almonds.'

ADAMANT

Sintered Oxide Tools Research

Wickman Ltd have recently announced the installation of a machine tool unit at their Research and Development Department, Upper York St, Coventry, for research into sintered oxide tools. The unit has a Max Mueller Eltromatic lathe of special design, a Heller FH 160 milling machine, and a Carlstedt deep hole boring machine. A toolmaking section enables test tools to be manufactured and modified rapidly for these machines and, additionally, provides tooling for the Wickman multi-spindle automatics, shortly to be installed in the department for further research and development work into the application of tungsten carbide tooling to automatics. The new department will be under the control of Mr. R. N. Cook, M.I.MechE., M.I.Prod.E.

*New Opinions on Grinding and Polishing especially of Metallographic Specimens**

Z. Ministr**

Introduction

The aim in grinding and polishing metallographic specimens is to obtain an even and smooth surface for the examination of the structure with a microscope, in such a manner that the structure of the material is not changed through the influence of pressure and heat. This, of course, is not easy, since in grinding and polishing these two factors are particularly effective.

It must be realized that a good and true photograph of the structure cannot be obtained even with the best microscope, if the preparation of the metallographic specimen is not satisfactory. It is not enough to obtain a lustrous surface; this surface must actually show the inherent structure of the material. The greater the magnifying power of the microscope, the better must be the quality of the metallographic specimens, and while microscopes have greatly improved in recent decades, grinding and polishing is mostly performed as it was fifty years ago[1]. In this article I want to call attention to some new findings and to summarize the most important principles governing grinding and polishing operations.

1. *The difference between grinding and polishing*

Every abrasive grain has relatively sharp cutting edges on the new fracture surface, but these are quickly rounded, thus obtaining a certain dynamic strength indispensable for grinding but at the same time losing the ability to take off very fine chips. Radius of curvature—as can be assumed—does not depend on grain size, which means that a very fine grain, after being blunted, has greater resemblance to a ball than to a sharp edged grain, and does not grind but polishes.

In an ideal case we should achieve a perfectly ground surface by a gradual, progressively finer removal of the material and by using a continously finer abrasive; but this cannot be done indefinitely. When following the dependence of the removed material on grain size (Fig 1) we find that a sudden decrease occurs at a certain grain size. After this the material is no longer removed from the surface to such an extent and in such a way as before, and a mechanical polishing begins in which the uneven spots are smoothed by a transfer of individual particles of the surface of the material (Fig 2).

The finest metallographic grinding papers have grains of a size from 10 to 30 microns. The roughness of the surface after having been ground with such a paper is 2 to 6 microns. By smoothing this, a Beilby layer (B-layer) is formed having a thickness of 1 to 3 microns, supposing, of course, that material is not removed from the surface during the polishing process. This supposition is not completely justified, but approximates closely to actual conditions. The B-layer, however, usually has a thickness of more than 1 to 3 microns, as the deformation is effective up to a greater depth. P. Gay and P. B. Hirsch[2] have shown by x-ray diffraction that the B-layer can have a depth up to 10 microns.

For these reasons, it is necessary to perform the final grinding with the finest possible abrasive at a low speed and in the presence of a fluid which conducts heat away quickly, the pressure being as low as possible.

2. *The origin of the B-layer*

As we have shown, it is not possible to use a successively finer abrasive indefinitely, since at a certain point mechanical polishing begins. During this, the uneven spots are smoothed and a B-layer forms which is probably thicker than half the height of the original unevenness. This layer often covers the original structure of the material and must be removed by one of the methods given below. It originates in the mechanical transfer of individual particles of the ground surface. In preparing metallographic specimens, the operator must first of all take care that this layer is as thin as possible. The thickness of the B-layer is directly related to the grain size of the finest abrasive. Hence the fine abrasive must be sufficiently hard, at all events harder than the ground material, for the cutting edges of the grains to remain sharp. The most common abrasive, alumina (alpha modification)[a], is easily blunted and the grains do not grind, but polish. If a grain is to be capable of fine grinding for an

* An abridgement of a lecture delivered in the metallographic exposition in Prague, organized by the Czech Scientific Technical Society for Metallurgy in the Czechoslovak Academy of Science, May 1956; *Hutník* 1956 Vol 6 (9) pp 257-262. Translated by B. Sudek.

** Powder Metallurgy Research Institute, Vestec, near Prague.

a) At 1200°C, modification gamma changes to alpha.

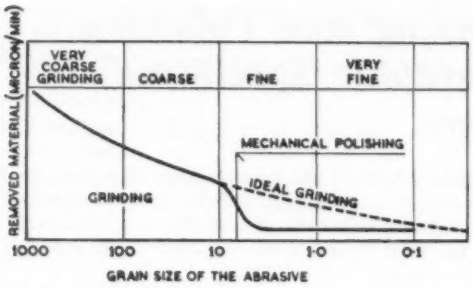

Fig 1. Dependence of material removed on grain size.

extended period, the radius of curvature of the cutting edge must be small and must not grow at a fast rate during the grinding process. In addition, the angle of the cutting edge must be as small as possible. The durability of grinding power is closely connected, as we have already mentioned[3], with the melting temperature of the abrasive and with its atomic concentration.[b] Diamond gives the most durable grinding power and also the greatest atomic concentration. Boron carbide follows, and then the oxides (Table I).

Table I. Melting temperature of grinding and polishing powders as compared with atomic concentration

Abrasive	*Composition*	*Melting temperature, °C*	*Atomic concentration*[b]
Diamond	C	3,700	0.293
Boron carbide	B_4C	2,450	0.227
Silicon carbide	SiC	2,200	0.167
Alumina (alpha)	Al_2O_3 (alpha)	2,050	0.191
Alumina (gamma)	Al_2O_3 (gamma)	1,200[a]	0.172
Magnesia	MgO	2,550	0.179
Chromic oxide	Cr_2O_3	2,270	0.171
Ferric oxide	Fe_2O_3	1,570	0.163

The angle of the cutting edge is closely connected with the crystallographic properties of the grinding material. Diamond grains have an almost ideal shape as these are almost equilateral triangular plates (Fig 3, 4).

In order to have the B-layer of maximum thinness, the abrasive must be as fine and as hard as possible and strongly bonded, as will be shown below.

During grinding and polishing operations, a relatively high temperature is generated on the surface, due to pressure and to the speed of the active grain, and mechanical transfer of particles is facilitated by means of this. Everyone has seen a stream of sparks during grinding operations, but few will believe that the temperature reaches some hundred degrees Centigrade, even in manual fine grinding and polishing, and even in the presence of a fluid. Bowden and Tabor[5] have already referred to the fact that repeated melting and solidification occurs on the surface during polishing, and that for this reason the melting point of the polishing grain is more important than its hardness. R. P. Agarwala and H. Wilman[6] have studied in detail the deformation of the surface of crystals of ferrous alloys during wet grinding. Electrolytically polished crystals of alpha-iron were reground by a single continuous movement, 25 cm in length, with a light hand pressure of about 50 g/cm², at a speed of 7.5 cm/sec, on a 0000 grinding paper flooded with benzene. After this single and relatively slow movement along paper with a grain size of about 30 microns, gamma-iron had formed on the surface during wet grinding. This was removed with relative ease and almost completely in ¾ to 1 minute by surface etching with a 1% solution of picric acid in alcohol. The formation of this modification of iron, which remained

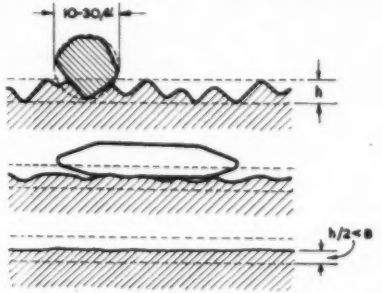

Fig 2. Origin of the B-layer during mechanical polishing.

stable owing to rapid cooling, clearly shows that the temperature had reached about 900°C on the surface.

B. Cina[7] has examined the ground surface of alloyed steel with x-rays and has shown that the real structure of steel could be revealed only by electrolytic polishing; this was concealed by a B-layer formed during the grinding operation.

At first, it remained unclear as to why no recrystallization and coarsening of the structure occurs during the formation of the B-layer, when the surface temperature becomes relatively high: in fact the exact reverse often occurs. The surface layer retains a very fine crystalline structure which is often harder than the lower layer and usually has the properties of deformed material. For example, with alloys of zinc or lead, recrystallization occurs at room temperature. In bearings having babbitts of these alloys, however, no recrystallization occurs, but

b) Atomic concentration is defined as the ratio of the product of density and number of atoms, and the molecular weight.

the reverse: a harder layer forms with properties of a cold strained material. B. Lunn[8] mentions in his study of the B-layer that good sliding properties are developed only by a harder B-layer on a softer support, and he expresses the view that chemical reactions of surface layers are responsible. He says that the B-layer is probably not entirely metallic and contains pressed-in harder metal oxides, as has been shown also by Moore and Tegart[9], and independently by Tonnesen[10]. Tonnesen found that a sliding layer in a bearing of zinc alloy contained a large amount of oxides after several metallic contacts, and had the typical appearance of a B-layer. According to the findings of these authors it can be assumed that the B-layer is really a fine mixture of metal and oxide similar to such sintered alloys as SAP[c].

It follows from these facts that mechanical polishing is not at all a suitable method for preparing a smooth surface. Consequently

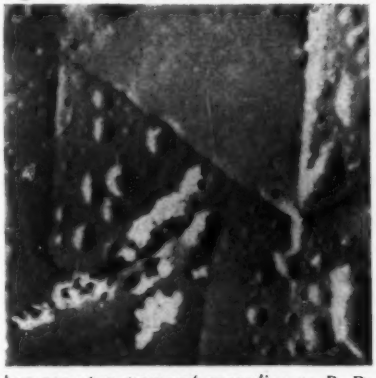

Fig 3. Surface of a diamond according to P. Ruzicka[4]— photograph made with an electron microscope.

great attention has been given recently to removal of the B-layer and to new methods of polishing.

3. *Removal of the B-layer*

There are many methods of removing the B-layer. Usually it is done by (*i*) chemical dissolution effected by surface etching, or (*ii*) electrochemical action, the source of electric current being the solution itself, which forms local electrochemical cells on the surface of the metallographic specimen, as in so-called chemical polishing. Alternatively the current is fed into the electrolyte from an external source, as in electrolytic polishing.

In chemical removal by surface etching, the surface of the metallographic specimen must first be mechanically polished. In electrochemical removal, however, it is sufficient for the specimen to be finely ground, since its surface is covered in the electrolyte by a special film, causing quicker dissolution of the ridges between scratches. The uneven spots on the surface are thus removed and the ground specimen is polished without forming a B-layer, as usually occurs in mechanical polishing.

In the most common surface etching, the surface can be dissolved either directly or indirectly. In indirect dissolution, the products of the chemical action adhere to the surface of the metallographic specimen. These can be removed either by mechanical action with the usual polishing process, using suspensions of oxides which have plate shaped grains, or by chemical dissolution in another bath.

In many cases, especially where electrolytic or chemical polishing has not previously been utilized, mechanical polishing and subsequent surface etching has normally been the most common method for removing the B-layer.

4. *Grinding or polishing with diamond powder*

Even though the B-layer can be removed by one of the methods given, it is important that its thickness should be small. With some materials, the above methods cannot be used; it is then very important that the B-layer should be as thin as possible, if the metallographic specimen is to be a true picture of the structure.

In this respect much work remains to be done on the limitations of the optical microscope. This microscope has a very small focal depth; hence the preparation of specimens with a smooth surface is necessary for structural examination. Very fine grinding of metallographic specimens is important for this reason. Diamond powder is the ideal abrasive for this

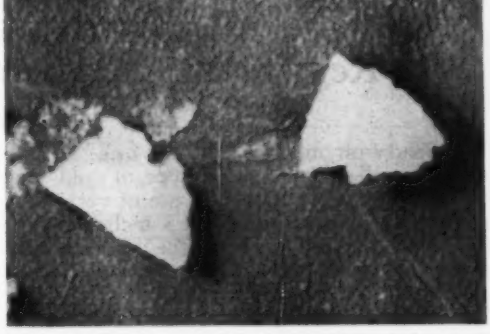

Fig 4. Diamond grains having a size of 2 microns according to P. Ruzicka[4].

c) SAP—sintered aluminium powder—is really a fine mixture of aluminium and alumina, produced by pressing and sintering a very fine aluminium powder which is oxidized on the surface. By subsequent straining, a material can be produced containing 10 to 20% of oxide and having essentially better properties, especially at higher temperatures, than have the best aluminium alloys so far known.

fine grinding process, as diamonds having a grain size of about 1 micron give a surface roughness of only some few tenths of a micron, *ie* less than the resolution of the strongest optical microscopes, and also less than their focal depth, the thickness of the B-layer being practically non-interfering. Thus, for example, using diamonds, Samuels[11] has attained unusually good results in surface grinding tin and zinc. It is well known how difficult and lengthy is the process of removing the B-layer from tin by alternately etching and polishing. A specimen of tin polished with diamonds has shown grain boundaries very clearly after only one etching. With zinc, the structure was distinct in polarized light after being polished with diamonds without subsequent etching.

In his comprehensive work[11], Samuels has studied the dependence of melting point on the removed material (in microns/min) and has found, in accordance with the theory of Bowden and Hughes, that the process of grinding or polishing is to a great extent affected by the relative melting points of the abrasive and the ground material; relative hardness is not important. He has shown that in grinding with diamonds there is some connexion between the removed material and melting point of the ground material. In his work he compares the loss in size of the metallographic specimen (in microns/min) during grinding with alpha-alumina (grain size of 10 to 30 microns) and with diamond (grain size of 4 to 8 microns) and, finally, during the electrolytic process. He remarks that diamonds have a much greater abrasive power than alumina, but also that the diminution of the metallographic specimen during electrolytic polishing of metals with a high melting point is greater than during polishing with diamonds, so that a smooth surface is achieved more quickly by electrolytic polishing of these metals.

Grinding and polishing with diamond has recently been given great attention[11,12,13,14]. It has not yet been precisely established how diamond removes material from the surface of a metallographic specimen, *ie* how diamond succeeds in removing material from the surface without forming the usual scratches, but, on the contrary, polishes the surface, forming only very occasional scratches.

I assume that this outstanding fact is a special characteristic of diamond, and is made possible by the unusually suitable shape of the grains—the triangular plates—which probably take off material from the surface with the action of small planes or scrapers. For a detailed explanation of the mechanism of polishing with diamond, it will be necessary to carry out precise measurements with analytical balances, x-rays and microscopes. We can certainly expect an extension of scope of metallographic microscopy through using diamond, although the possibilities of using mechanically polished specimens for an examination of structure will be limited.

The only disadvantage of fine grinding with diamond is that diamond abrasive is a very expensive and rare material. But when it is considered that the fine grinding of one specimen of a hard material, such as sintered carbide, costs, according to the size of the ground area, from 0.10 to 0.50 Kcs (1d to 6d), we see that the cost of a photographic plate and paper for making a single photograph is much higher than that of the abrasive, the better quality and efficiency not being taken into account. The cost will be proportionally smaller in grinding softer material and the possibility of diamond being blunted by grinding can be disregarded. Destruction of the paper support occurs first through contamination by a coarser abrasive, or by an incorrect holding of the specimen, the paper being quickly worn off or even torn.

(To be concluded)

*Regrinding Sendzimir Mill Work Rolls**

Albert I. Palm

The Sendzimir mill, or ' cluster mill ' as it is commonly called, is a unique type of cold strip mill in that it incorporates the use of very small work rolls ranging from ¼ to 3 inches in diameter. The arrangement of the various rolls and bearings in the top and bottom roll clusters is clearly indicated in Fig. 1.

It will be seen that the small work roll in each cluster is supported by two intermediate rolls and backed up by three second-intermediate rolls which are power driven; these, in turn, by four rows of antifriction bearing casters. As the work rolls are positively supported along their entire length, the rolled strip can be held to extremely close tolerances of gauge. Moreover, because the area of contact between the small diameter rolls and the strip is very small, so that the strip is free to elongate, the Sendzimir mill is capable of reducing material as much as 30% and more per pass on 0.010 down to 0.004 inch gauge material and lighter.

*Grits & Grinds 1957 Vol 48 (5) pp 3-8 (May)

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The materials commonly handled include carbon and stainless steels, non-ferrous metals like brass, copper and aluminium alloys, and, more recently, tantalum.

Work roll sizes and composition

Sendzimir mill work rolls vary from as small as ¼ inch in diameter and 8 inches long for rolling ultra-thin steel strip to 3 inches in diameter and 48 inches long. Some typical rolls used in actual installations measure 1½ inches in diameter × 25 inches long for rolling stainless steel strip; 7/8 inch in diameter × 17 inches long for rolling Inconel; 2 inches in diameter × 40 inches long for aluminium alloys, and 2 inches in diameter × 48 inches long for both low carbon and stainless steels.

The work roll material is generally either a high-speed steel or a high grade tool steel of the high-carbon, high-chromium or high-vanadium variety. Intermediate rolls are usually of the high-carbon, high-chromium type. Sintered carbide work rolls are being used to an increasing extent because of their extremely high productive capacity between regrinds.

Grinding wheel recommendations

The wheels used for regrinding Sendzimir mill work rolls will vary somewhat according to the size of the roll and the metal to be rolled, which in turn determines the finish required on the roll.

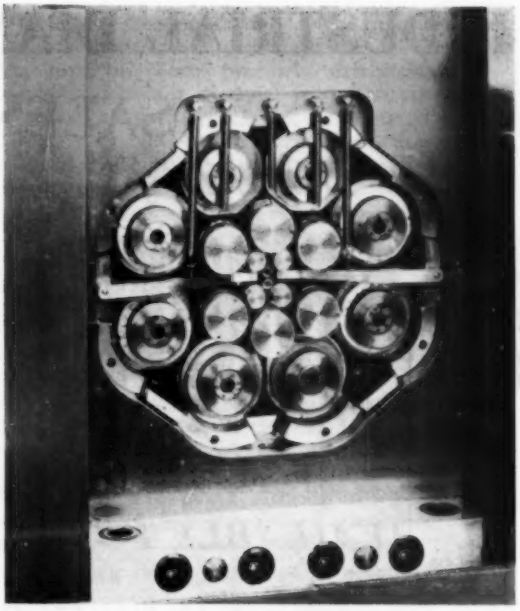


Fig 1. Close-up of interior of small mill for rolling ultra-thin strip to 0.0005 inch. Note pair of work rolls at very centre.

Fig 2. General view of typical Sendzimir mill with door of mill housing open to show the roll clusters. Note upper work roll leaning against mill.

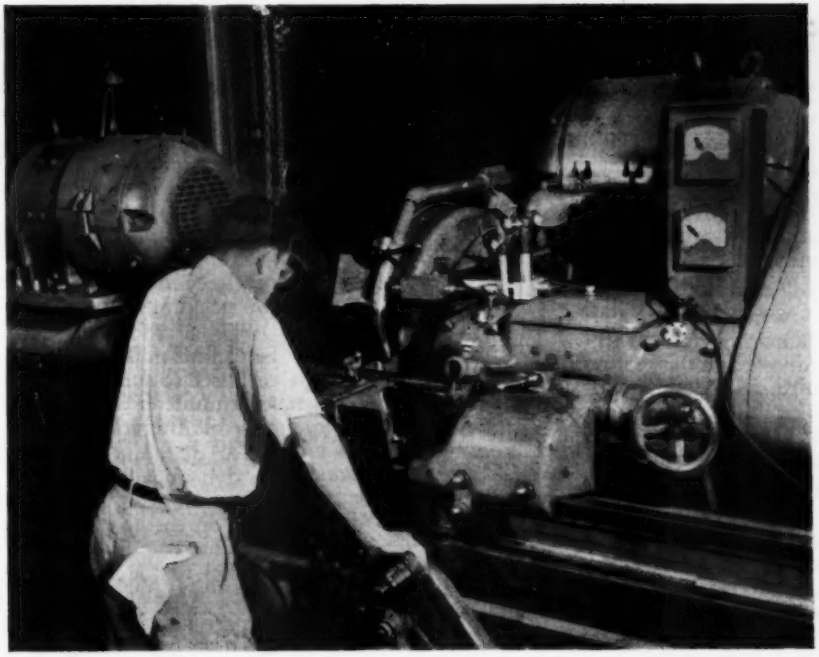


Fig 3. Regrinding a carbide Sendzimir mill work roll with 1500 mesh diamond wheel. Instrument at lower right is wheel load ammeter.

Intermediate or back-up rolls, usually made of high-carbon, high-chromium steel, are generally reground with a 60 mesh silicon carbide vitrified wheel, such as 37C60-HVK. This wheel will give a good commercial finish which as a rule is considered satisfactory. If a finer finish is desired, a 180 mesh wheel such as 37C180-G10V is recommended.

Grinding hints

To obtain the best possible results in regrinding Sendzimir mill work rolls, the following precautions should be observed:

(1) Use a single-point, sharp diamond for truing and dressing.
(2) The grinding wheel and sleeve assembly must be in good balance.
(3) The grinding machine must be in the best possible condition and free from vibration.
(4) Allow the grinding machine to warm up for at least a half hour before starting to grind. Do not attempt to grind while the machine is cold.
(5) Use a relatively low wheel speed of 3,000 to 4,000 ft/min. Higher wheel speeds up to 6,500 ft/min are sometimes used with satisfactory results, but are more likely to cause chatter marks on the roll surface.
(6) The coolant must be carefully filtered to exclude any foreign particles that could cause scratches. For the same reason, the inside of the wheel guard should be flushed periodically. Two coolant tanks may be desirable, one to be used for rough grinding and the other reserved exclusively for mirror finishing. With this dual tank arrangement, scratches on the roll surface that might be caused by dirty coolant are eliminated.
(7) Do not attempt to grind long slender rolls without steadyrests.
(8) Rough grind when 0.001 inch or more stock has to be removed. Leave less than 0.001 inch stock for finish grinding.
(9) Some operators apply a Prussian blue coating to the roll preliminary to finish grinding. The film-like coating is removed by taking the lightest possible cuts. The technique calls for skill and judgement on the part of the machine operator.
(10) An ammeter on the wheel spindle drive motor is important when regrinding Sendzimir mill rolls in order to maintain a constant pressure between the wheel and the work and thereby ensure dimensional accuracy throughout the length of the roll.

Work rolls for tantalum sheet

These are in the smallest size category—$\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter and 6 to 10 inches long. They are refinished by the following lapping

method to produce the extremely fine finishes and close dimensional tolerances required.

Two parallel copper rolls, one 4 and the other 7 inches in diameter, slightly separated, are rotated at different speeds. The work roll to be lapped is laid between them. Diamond lapping paste, diluted with paraffin, linseed or olive oil, is brushed on the copper rolls. By exerting pressure on the work roll, it gradually acquires an extremely high finish with very close dimensional tolerances.

Roll calipering devices

While the conventional method of manually calipering rolls with a micrometer is largely followed in the regrinding of Sendzimir mill rolls, ultra-precision electrical measuring instruments like the P. & W. Electrolimit gauge and Dynamaster recorder which measure to millionths of an inch are coming into increased use.

Carbide work rolls

Sendzimir mill work rolls of sintered carbide, in spite of their initial high cost, are being used to an increasing extent because of the much greater tonnage that can be rolled between regrinds. They are reground with diamond wheels, generally 12, 14 and 24 inches in diameter by 1 inch thick.

The following specifications for regrinding carbide work rolls are recommended, according to the operation and the finish required on the roll surface:

Finishing: D320-L100B (for rolling carbon steels to 5 to 6 rms).

Fine finish: D 600-L100B (for rolling razor blade steel strip and carbon steels to 2 to 4 rms).

Ultra-fine finish: D 1500-J25B (for rolling stainless steel strip with mirror-finish to 1 rms).

Do not use wheels any finer than necessary to produce the finish required on the rolled material. Unnecessarily fine surfaces may cause trouble from roll slippage.

The following data taken from an actual carbide roll grinding job will indicate the procedure followed. The rolls in this case were 3 inches in diameter × 10 inches long. The data would apply to any of the previously recommended fine mesh sizes of diamond wheels.

Table I.

Operation	*Wheel speed*	*Roll (3" dia) speed*	*Table traverse*	*Grinding pressure*
Rough grind	4,000 ft/min	100 rpm	60 in/min	18 to 23 amperes
Finish grind	4,000 ft/min	100 rpm	Slowest available	Lightest possible

Grinding hints

Clear water is used as a coolant; any soluble oil in the water would cause the wheel face to smear and stop cutting completely. The presence of any chlorine in the water should be noted and steps taken to counteract its pitting action on the carbide roll by adding wood alcohol to the coolant.

A wheel load ammeter, and also a wheel speed tachometer (on DC wheel drive), is considered indispensable when using very fine mesh diamond wheels to produce mirror finishes in roll grinding. By using this technique of grinding 'by instruments', the operator has precise and sensitive control over the action of the grinding wheel at all times.

Fig. 3 shows a carbide work roll for a Sendzimir mill being reground. Note the steady-rest used to support the slender roll and the wheel load ammeter (lower right) by which the operator controls the grinding pressure.

The diamond wheel and sleeve assembly must be dynamically balanced, and the wheel must run in almost perfect truth. To prevent feed lines on the roll surface, the work centres must be scored and the table must move absolutely parallel to the wheel face. Finally, the corners of the wheel face should be rounded slightly.

Very light increments of wheel feed must be taken, as otherwise deep burns may be produced in the roll, and these would be very difficult to remove.

The rate of production possible in regrinding carbide Sendzimir mill work rolls with diamond wheels is indicated by the report from an Eastern plant where rolls 2 inches in diameter × 30 inches long are ground at the rate of seven rolls per 8-hour shift, with a 1,500 mesh diamond wheel.

Ring lapping with diamond paste

When thus regrinding carbide rolls that are to be used for rolling stainless steel strip, minute feed lines and traces of chatter marks may show up. To completely eliminate these flaws, however slight, it may be necessary to resort to ring lapping with diamond paste.

This procedure calls for the use of a cast iron circular lap which is made just to fit over the roll. In use, the lap is traversed manually back and forth across the roll with diamond paste for the cutting medium. A relatively coarse size paste such as No. 24 is used for roughing, and a finer size paste, No. 8, for finishing. The lap must never be allowed to stop on the roll as otherwise the diamond particles may dig in and leave scratches which will be difficult to remove. As compared with grinding, this hand lapping operation is very slow and may take as long as four hours to produce the final 1 rms finish on a 2 inches in diameter × 30 inches long carbide roll.

A. I. PALM

Accurate Measurement of the Hole Size of Fine Gauge Diamond Dies

W. R. Moyers and G. M. McLeod**

The Tonawanda plant of Western Electric produces over 20 million miles of fine copper wire annually, some as small as 0.002 inch in diameter. To do this job, over 10,000 diamond dies are resized each year.

The standard tolerance on copper wire diameter and consequently on the dies is ±1% of the nominal diameter in sizes to 0.010 inch (30 gauge). Wire smaller than this has a tolerance of ± 0.0001 inch. This provides a linear relationship for diameters that vary geometrically.

Investigations into wire tolerances showed that at present it is impractical to provide a non-linear decrease in tolerance to match the decrease in gauge sizes. However, it was decided that the quality of the apparatus using the wire could be improved by cutting in half the allowed wire tolerance of some of the fine gauges. The tolerance of ± 0.00005 inch on the nominal wire diameter was established for wire sizes from 0.005 inch diameter and smaller. (With this reduction, however, it proved impossible to measure wire diameter accurately, with a screw type micrometer.

Other methods of measuring were investigated, but with one exception all had faults that prevented their use in a production operation that required accurate information to be obtained merely by semi-skilled operators, in the least possible time and under conditions detrimental to delicate apparatus.

The exception was found in weighing a measured length of sample wire on precision balances, accurate within 0.2 mg. Using standard physical constants, this was a relatively simple procedure.

A simple formula was derived for computing the weight of a known length of any diameter wire. The theoretical American wire gauge diameters were calculated and used in this formula, giving a table of weights for each gauge size. The wire tolerances were calculated in the same manner using ±1% for 35 gauge and larger and ±0.00005 inch for the fine gauge wire.

The average diameter of a wire produced by a die could now be determined by weighing measured lengths. However, experimental trials, weighing wire produced by a wire drawing machine as compared with wire pulled through the same finish die by hand, showed a variation, due to the fact that an operator could not pull a relatively long wire sample through a die by hand without varying the pull on the wire.

Hand-powered drawing machine

To overcome this problem in the die shop, a simple hand powered wire drawing machine was made. This consists of a die holder, a pulling capstan and a measuring wheel, with the capstan and measuring wheel driven together. (Fig 1). Diameters of the refinished diamond dies are checked on this machine by drawing a wire of the next larger gauge through the die opening. It is then wrapped around the capstan and fastened to the measuring wheel. The sample is taken by turning the measuring wheel the number of turns specified on the master chart for the gauge size being checked. A slot in the measuring wheel is provided so that the turns of wire are cut simultaneously. This provides several lengths of wire of exactly the same length. The number of samples or total length of sample wire varies with the diameter. By doing this, sample weights are produced that fall within the range of the precision balance used for weighing the sample.

Fig 1. The die shop measuring equipment for fine gauge wire has flexibility. The various gauges of supply wire are arranged on a rack for maximum convenience. Dies being checked are threaded with wire and placed in the die holder. The wire sample is taken, weighed and compared to the gauge weight chart and recorded on the die envelope.

* Paper presented at the Annual Convention of the Wire Industry in Chicago, October 15, 1957. Abridged by permission of the Editor from *Wire & Wire Products* (1957 Vol 32 (10) pp 1219-1210, 1273 (Oct)), who also made blocks available.

** Western Electric Co, Tonawanda, NY

Fig 2. Heavy gauge wire is pulled through the larger size diamond dies by this rack-and-pinion and pulling jaw. Samples are weighed, compared with the master chart, and recorded on the envelopes containing the dies.

With the average wire diameter determined accurately by weight, roundness is checked with a barrel micrometer, which is sufficiently accurate to measure the roundness of the wire, since in this case the micrometer is being used only as a comparator and not for measuring absolute values.

Although this system was developed primarily for fine gauge wire, a second wire sample machine was made for the intermediate wire sizes so that all diamond dies could be checked by this method. The design of this second machine differs from the fine wire machine in that the wire is pulled through the die by a clamping jaw actuated by a rack and pinion. Sample lengths are cut by tungsten carbide shears operated simultaneously. Only one length of the larger diameter wire is needed because of its greater weight per length (Fig 2).

The actual wear of diamond dies in the wire drawing machines is checked (Fig 3) each day by the wire mill inspection organization. The inspector is provided with a measuring wheel and micrometer and obtains samples periodically from each wire drawing machine. The correct length is taken and placed in a marked envelope and the remaining wire is checked for roundness. These sample lengths are then weighed. By checking the finish die wear in this matter, the dies can be used until they approach very closely their limits for oversize wire.

Weighing wire samples has increased die life. The accuracy of this method has provided a tool that allows closer resizing of the dies. It is therefore possible to start the dies closer to their minimum allowable size, and gain the advantage of greater die life by continuing their use to near the maximum diameter.

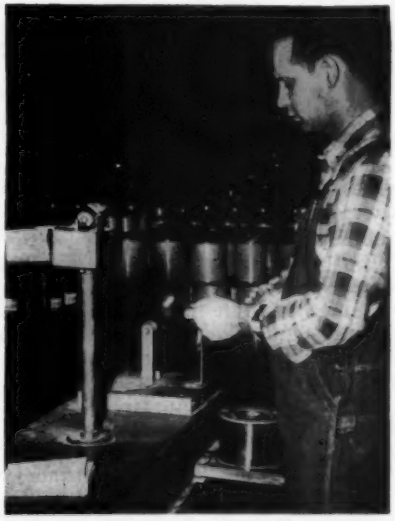


Fig 3. Inspection of diamond dies in the wire mill is facilitated by mounting all of the inspection equipment except the torsion balance on a cart that may be moved to the wire drawing machine being checked.

Automation Exposition and Congress

The 4th International Congress will be held in New York from June 9-13, 1958. Apart from the exhibition itself automation clinics (each class comprising a 90 minutes lecture and demonstration based on operating equipment exhibited at the Exhibition) and technical sessions are planned. There will additionally be three conferences on 'Automatic data processing for senior executives', 'Human factors in systems engineering', and 'Plant Layout : technical workshop'. All inquiries to Richard Rimbach Associates, 845-A Ridge Avenue, Pittsburgh 12, Pa., USA.

Spark-Machining Film

Wickman Ltd. of Coventry will shortly have copies available of a new 16 mm colour film "The Wickman Erodomatic", which runs for about 17 minutes, beginning with an animated sequence on the nature of spark machining and illustrating the equipment necessary for the process, with a description of the two Erodomatic models currently available. The next sequence gives a demonstration of the operations necessary for some typical jobs, and the film is concluded with various production examples. Inquiries for loan should be made to the Company.

An Ultrasonic Drill for Boring Small Holes in Hard Materials

N. K. Marshall*

Introduction

A new technique for the ultrasonic drilling of small diameter precision holes in glass-hard materials such as ceramic magnets and ferrite cores is described and demonstrated. A specially shaped waveform is used to drive a magnetostriction transducer at an operating frequency of 28 kc/sec to produce a rotating 'jack-hammer' action which speeds up the drilling process and increases the accuracy of the finished hole.

A diamond-paste loaded brass drill, 0.015 inch in diameter, is loosely held in the transducer head and is driven into an automatic rotary motion by the special waveform. High precision straight holes of uniform diameters as small as 0.005 inch are produced with good repeatability.

(1) *Statement of problem*

The problem was to drill four accurately spaced straight 0.015 inch diameter holes through the side of a core of a very hard and brittle vitrified iron-oxide compound which has drilling and machining characteristics similar to glass, and a Mohs' hardness of about 7.

A clean, straight, cylindrical bore hole, accurately positioned and perpendicular to the magnetic field of the core, was required. This called for precision drilling of a type which our shop is quite accustomed to doing when using steel or brass, but never before accomplished by us in a glass-hard brittle material such as this.

(2) *Drilling methods attempted*

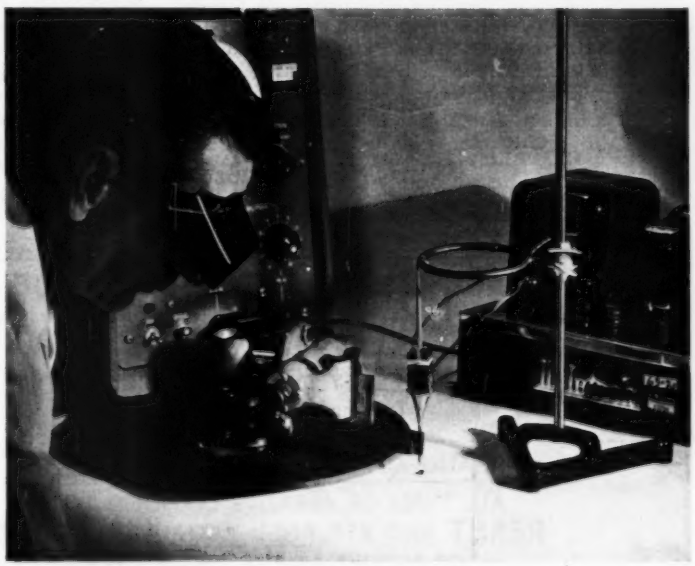
In an attempt to drill such holes, the shop broke dozens of No 80 drills and burned up diamond-charged brass and copper wires, at both high and low speeds, scarcely making a dent in the core surface. Considerable time and effort was expended in trying to find an air abrasive technique to accomplish this purpose. This technique, too, proved unsuccessful when it became obvious that control could not be maintained over either the hole diameter or direction. Finally, a single hole was drilled through a sample core, but it turned out looking like a funnel and completely unsatisfactory for the purpose. Several acid etches, diamond-point drills, and pointed abrasive rods were tried with unsatisfactory results.

A search of the literature was made to determine whether anyone else had a good approach to this problem, but none was found.

(3) *Solution and fabrication procedure*

By far the most useful contribution was made by the discovery of an envelope containing about a hundred die-stamped permendur laminations, used on a magnetostriction hydrophone design about 4 or 5 years ago.

These laminations were originally punched out of 0.015 inch sheet permendur and had been hydrogen-annealed. The physical dimensions and configuration had been specifically designed for use on a 24 kc low-impedance listening hydrophone. As these laminations appeared to be in good enough condition, they were used as a basis for the construction of a small ultrasonic



General view of test set-up.

* Telecommunications Department, Lockheed Aircraft Corporation, Missile Systems Division, Palo Alto, California.

drill. Naturally, any suitable magnetostrictive core material can be used for the same purpose.

An exponential-horn type of driver design was selected for use as a bit holder. Dimensions were calculated using the velocity of propagation of sound in brass. A sketch of the completed design was turned over to an experimental machinist for fabrication. The most difficult part of the whole job was to get a true exponential taper on the brass horn and a well-centred hole for the drill bit. The machinist turned out three or four pieces before producing one that appeared satisfactory. Actually, it appeared later that any one of the rejects would probably have done. Meanwhile, the individual laminations were cemented together into a stack with a thermo-setting cement. A thinned solution was made by adding thinner until a water-dip consistency was obtained. After dipping, each lamination was stacked in place. Two small clamps were applied (over wooden protectors on each side of the laminated stack to prevent warping due to localization of pressure from the clamp jaws) and were tightened just enough to squeeze out any excess cement. The stack edges were wiped clean with a rag moistened in pure solvent. The cement was cured in an oven at 250°F (120°C) for a period of two hours. The exponential cone was next cemented to the bottom of the permendur stack using Araldite (Ciba product) stick cement. (Several other good, low-shrinkage thermosetting cements such as Shell Epon, Bakelite, G.E., Monsanto etc might be equally suitable). This also was cured in the oven at 250°F for two hours. The brass cone was held in place during the curing cycle by its own weight, the cone pointing upwards.

The complete assembly was removed from the oven, allowed to cool, then wound loosely with No 28 Formvar (or Ceroc) wire. About fifty turns were wound around each pole of the stack assembly. Care must be exercised in the winding process to ensure freedom of movement of the core inside the winding. If the wire is too tight on the laminations, there will be a restriction, and subsequent heating will occur when the driving voltage is applied. The coil impedance should match that of the output transformer of the driving amplifier at the operating frequency to ensure maximum transfer of energy. However, this is not too critical, and even a 2 to 1 impedance mismatch can be tolerated without serious power losses. In the case at hand, the resonant impedance turned out to be 8 ohms at 24 kc.

A generous coating of Duco household cement was used to keep the coil windings rigid. The coils themselves were wound over several turns of thin Teflon sheet which had been wound over the pole pieces to serve as a spacer for the windings. This sheet was removed after the Duco cement had hardened (about 30 minutes under a 10 watt bulb). A flexible connecting cable about three feet long was made next and fastened to the coil. A ferrite magnet was placed in the transducer air gap; this magnet has a transverse field of about 30 gausses and is polarized in the thickness mode.

(4) *Description of drill*

A thin brass rod, 0.013 inch in diameter and 1½ inches long, was fabricated and loosely fitted into the 0.020 tool-bit hole located in the end of the brass exponential cone. The difference in sizes between the brass drill rod and the tool holder hole allows freedom of rotational movement of the drill inside the bit.

The completed assembly was next suspended from an adjustable bracket by means of a resilient support (spring or rubber-band) in such a manner as to allow the drill rod just about to balance the weight of the entire transducer assembly on the thin point.

The driving oscillator (or waveform generator) can be any suitable laboratory instrument capable

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of producing square or triangular waves at 20 to 30 kc. For this purpose a model 211A Hewlett-Packard generator was used. To satisfy the requirement for a 20 to 40 watt power amplifier, a McIntosh model Mc 30, rated at 30 watts, was employed.

An overall view of the test set-up is on p. 17.

The parts to be drilled, several tiny ferrite cores, are placed on top of a 2 inch square piece of 1/4 inch plate glass, cemented on with Duco household cement and allowed to dry for 30 minutes. The glass is then set on top of a similar sized mirror, so that the bottom of each core can be observed to determine when the drill has cut through.

(5) *Drilling procedure*

To drill a hole, the drill is carefully centred on the exact spot where the hole is to be drilled. The amplifier is turned up to a level of about 10 to 15 watts. The oscillator frequency is varied slowly until a fine dust appears at the point where the drill touches the ferrite core. Next, the oscillator frequency is adjusted for maximum cutting action. It will be seen that the hole is started dry, without abrasives. This procedure gives greater accuracy of hole location, even though it takes a little longer to get started. It also requires the use of a diamond-charged drill (one that has previously been used).

As soon as a noticeable dent appears on the ferrite's surface, a small amount of diamond paste is applied to the work, with a toothpick applicator. This tiny bit of abrasive will last about three or four minutes, after which more is applied. This procedure is repeated until the hole has been drilled completely through the core. The amplifier gain is raised slightly after the hole has been started and the waveform generator readjusted so that a rotary action of the drill is obtained. When properly adjusted, the 24 kc up-and-down motion of the drill, coupled with this automatic rotary action, will drill a 0.090 inch deep hole accurately and perpendicularly through the ferrite cores, in an average time of 6 minutes. The hole diameters measure 0.015 inch ±0.0015.

Drill bits can be used for about 10 holes, after which hole sizes begin to fall below tolerance. Since the drills are relatively inexpensive and easy to make, the operator can be kept supplied with several spares. An emergency drill can be made within an hour or so if some special size is needed.

After four holes have been drilled, the core is removed from the plate glass holder with a razor blade and immediately slipped on to a paper clip to avoid loss. The Duco cement is dissolved in a solvent and the little core is ready to be hand-wound with No 48 wire.

If a production quantity of these cores were desired, the equipment would, of course, be redesigned to drill all four holes simultaneously and automatically. The process described here is useful only for small laboratory quantities and is primarily intended for experimental use where several different sizes or a small number of the same size holes are needed.

(6) *Future development*

An air-driven high-speed rotary motion ultrasonic drill is at present being used experimentally for drilling holes in industrial diamonds. Several other novel configurations for providing rotary motion are also being investigated.

Acknowledgement

Thanks are expressed to Arthur S. Knapp of Lockheed's Molecular Aerophysics Department who helped to set up and develop this new drilling technique, and without whose patience and skill this project could not have been completed in such a short time.

N. K. MARSHALL

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